N91-14410

InAsSbBi, A Direct Band-gap, III-V, LWIR Material

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ABSTRACT

There has been extensive progress in the last twenty years in the growth of device quality III-V mixed alloys. Most of this work has centered around the wider band-gap alloys like AlGaAs and InP. In the last several years some of this effort has been extended to the narrower band-gap InAsSb system. This ternary has a direct band gap ranging from 145meV for $InAs_{(0.35)}Sb_{(0.65)}$ to 415meV for InAs with the other end point being at 235meV for InSb. It is possible to lower the band gap even further by adding bismuth. Bismuth is a large atom and its equilibrium solubility is estimated to be only 0.02 % in InAs and 2 % in InSb. Several attempts at adding 1 to 2 % Bi to III-V alloys by LPE or MBE have shown poor quality material with phase separations and precipitates.

In the last several years Dr. Stringfellow's group at the University of Utah has reported success in incorporating over 3 % Bi in InAs and 1.5 % in InAsSb using OMVPE growth techniques. For InAs the lattice constant increase is linear with a=6.058+0.966x ($InAs_{(1-x)}Bi_{(x)}$), and a decrease in band gap energy of dEg / dx = -55meV / at % Bi. (1) Extrapolating this to the ternary minimum band gap at $InAs_{(0.35)}Sb_{(0.65)}$ an addition of 1 to 2 % Bi should drop the band gap to the 0.1 to 0.05eV range (10 to 20 microns). These alloys are direct band gap semiconductors making them candidates for far IR detectors. The end points InAs and InSb are used extensively as MWIR detectors now.

The current status of the InAsSbBi alloys is that good crystal morphology and X-Ray diffraction data has been obtained for up to 3.4 % Bi. The Bi is metastable at these concentrations but the OMVPE grown material has been able to withstand the 400 C growth temperature for several hours without phase separation.

The electrical evaluation of the material has only just started. Hall data on OMVPE InSb has shown an n-type mobility of greater than 20,000 cm2 / V-sec at 200 K and carrier concentrations in the low E14 range. The ability of these alloys to show luminescence implies reasonable electrical quality over the range of alloy studied. (2) Both luminescence and transmission have been used to determine the change in band gap with Bi concentration. Some increase in the luminescence band width is seen with increasing Bi suggesting some compositional variation. Alloys have been grown near the InAs end with up to 30 % Sb. InSb has also been grown by OMVPE but the low band gap region has not yet been explored. At present there is no optical detector data on these alloys.

This effort is to continue with Dr. Stringfellow's group at the University of Utah growing material and with Santa Barbara Focalplane extending the material characterization and starting the processing of test detectors and arrays.

REFERENCES

1. "Organometallic Vapor Phase Epitaxial Growth and Characterization of InAsBi and InAsSbBi", K. Y. Ma, Z. M. Fang, D.H. Jaw, R. M. Cohen and G. B. Stringfellow, Appl. Phys. Lett. 55(23), 2420 (1989).

2. "Photoluminescence of InAsBi and InAsSbBi Grown by Organometallic Vapor Phase Epitaxy", Z. M. Fang, K. Y. Ma, R. M. Cohen, and G. B. Stringfellow, To be Published, J. Applied Phys. (1990).

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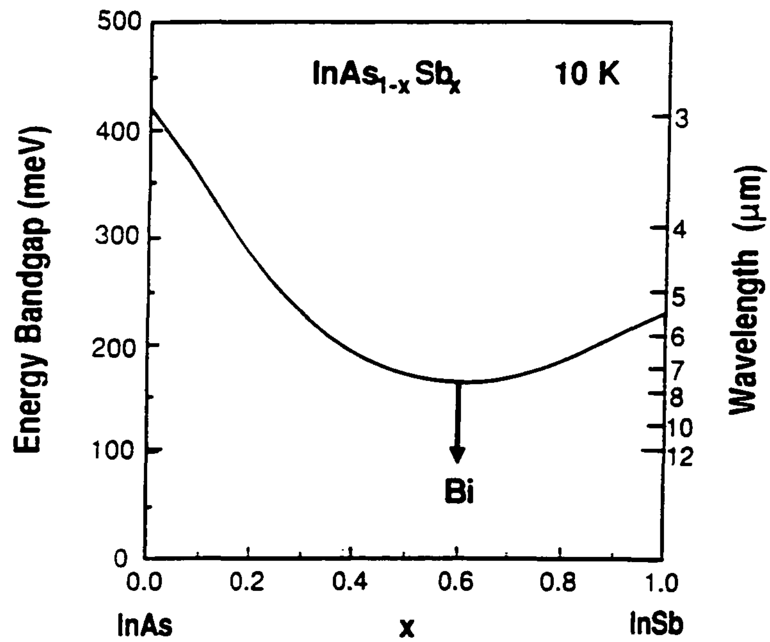
REASONS FOR INTEREST IN InAsSbBi

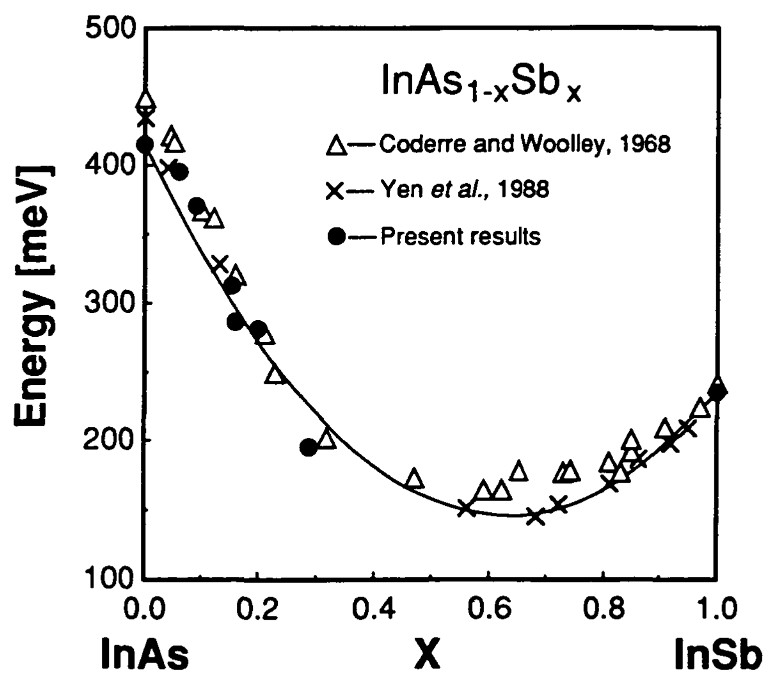
1. DIRECT BAND-GAP SEMICONDUCTOR

2. GAP TUNABLE FROM <0.05eV TO 0.415eV

3. EXTENSION OF CURRENT OMVPE III-V MATERIALS GROWTH TECHNOLOGY PRODUCING DEVICES IN GaAs, AlGaAs, InP ......

Energy Bandgap vs. Composition x





- **SOLUBILITY OF Bi IS LOW**

  2.1% IN InSb, 0.02% IN InAs

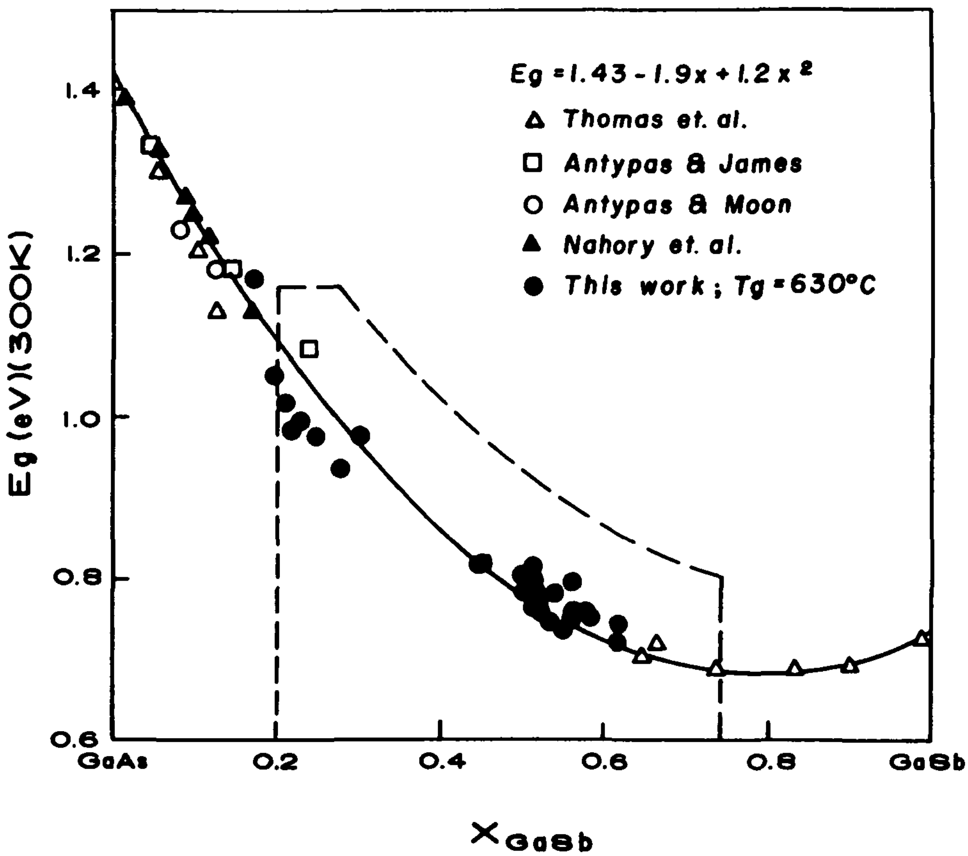
- **OMVPE GROWTH HAS BEEN ABLE**

  TO GROW METASTABLE COMPOSITIONS

  OF MANY ALLOYS AND OF Bi IN InAsSb

METASTABLE III/V ALLOYS GROWN BY OMVPE

Alloy	T_c(°C)	Range of Immiscibility	Reference
GaAsSb	750	0.2-0.8 (600°C)	Cherng et al (1984) Univ of Utah
GaInAsSb	1467	90% of Phase Field (600°C)	Cherng et al(1986) Univ of Utah
InPSb	1046	0.03-0.98(460°C)	Jou et al (1988) Univ of Utah
GaPSb	1723	0.01-0.99(540°C)	Jou et al (1988) Univ of Utah

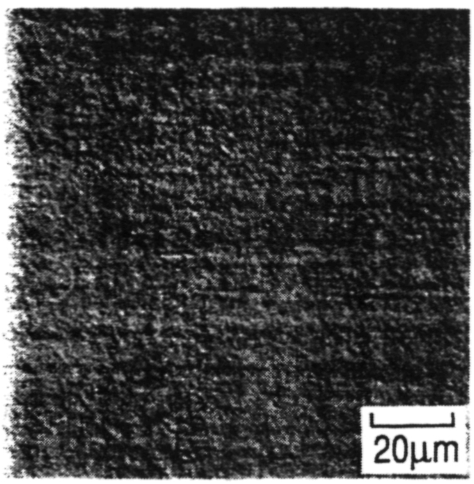


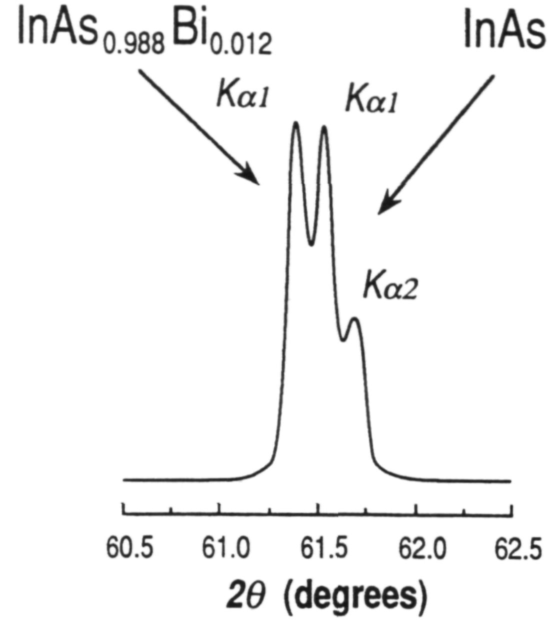
SANTA BARBARA FOCALPLANE

A NUMBER OF GROWTHS HAVE BEEN MADE FOR

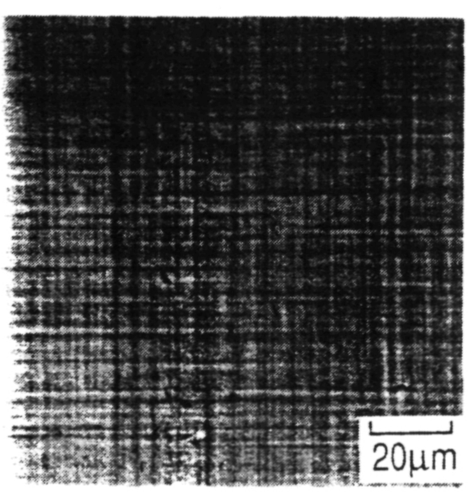
InAsBi AND InAsSbBi

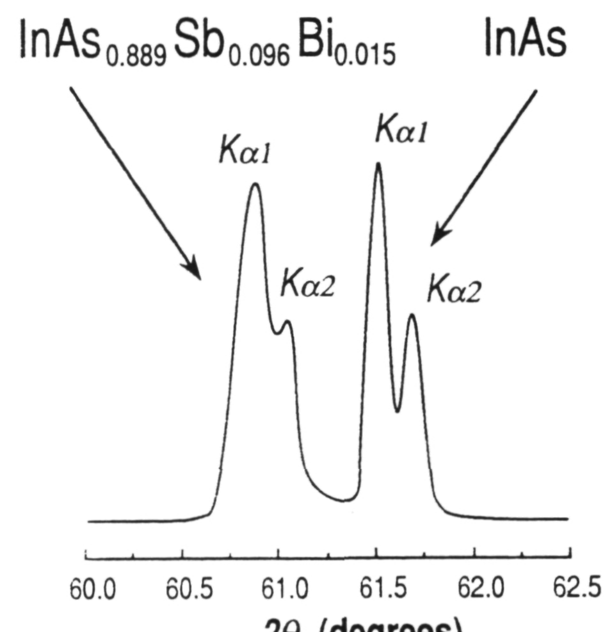
TO UP TO 3% Bi AND 30% Sb


20μm

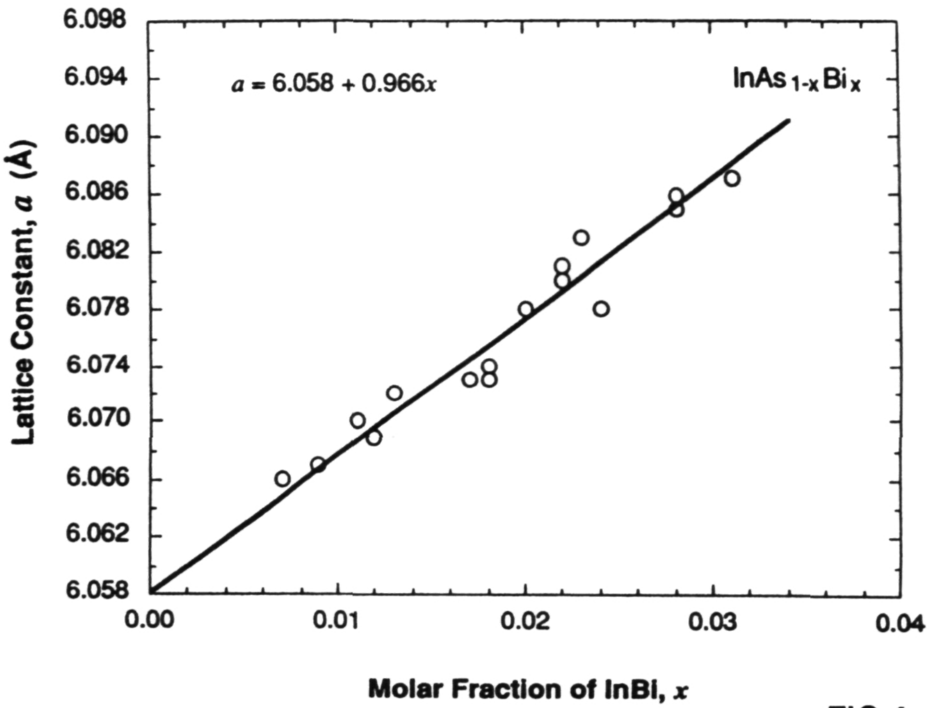

$InAs_{0.988}Bi_{0.012}$
InAs
$K\alpha 1$
$K\alpha 1$
$K\alpha 2$
60.5 61.0 61.5 62.0 62.5
2θ (degrees)

(a)


20μm

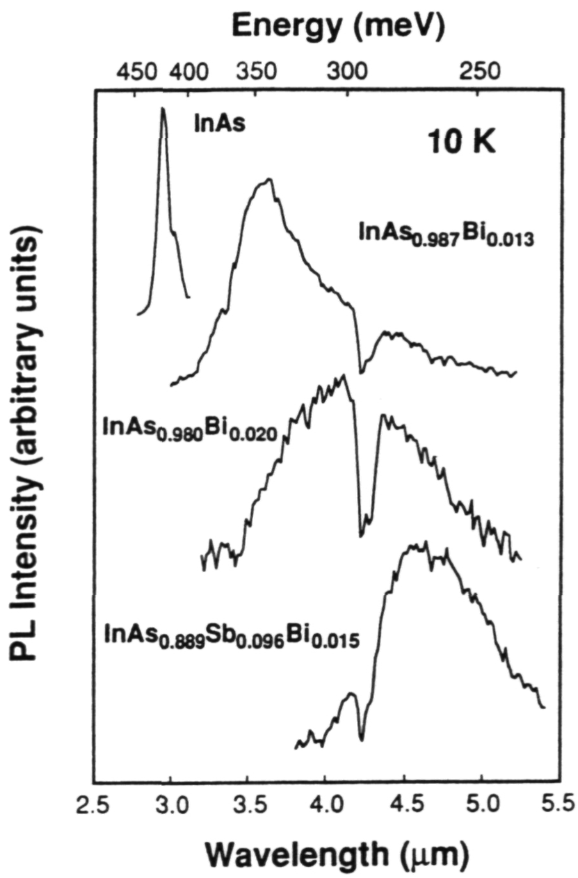

$InAs_{0.889}Sb_{0.096}Bi_{0.015}$
InAs
$K\alpha 1$
$K\alpha 1$
$K\alpha 2$
$K\alpha 2$
60.0 60.5 61.0 61.5 62.0 62.5
2θ (degrees)

(b)

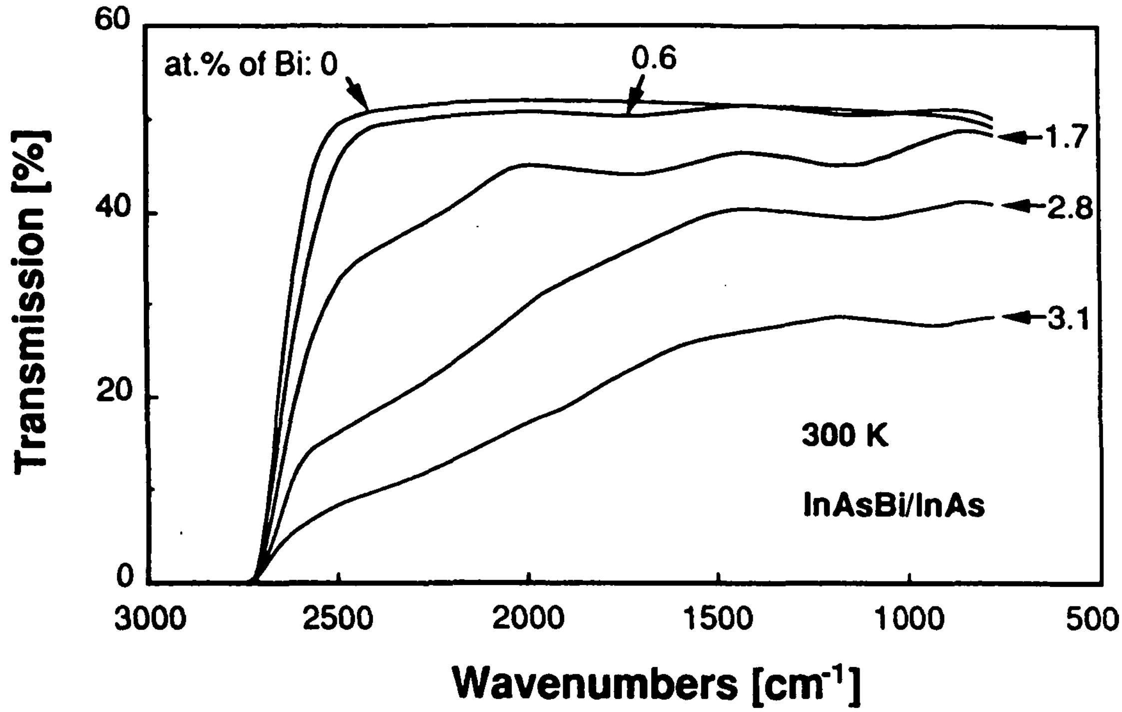


a = 6.058 + 0.966x
InAs 1-x Bi x
Lattice Constant, a (Å)
Molar Fraction of InBi, x
6.098
6.094
6.090
6.086
6.082
6.078
6.074
6.070
6.066
6.062
6.058
0.00
0.01
0.02
0.03
0.04

FIG 4

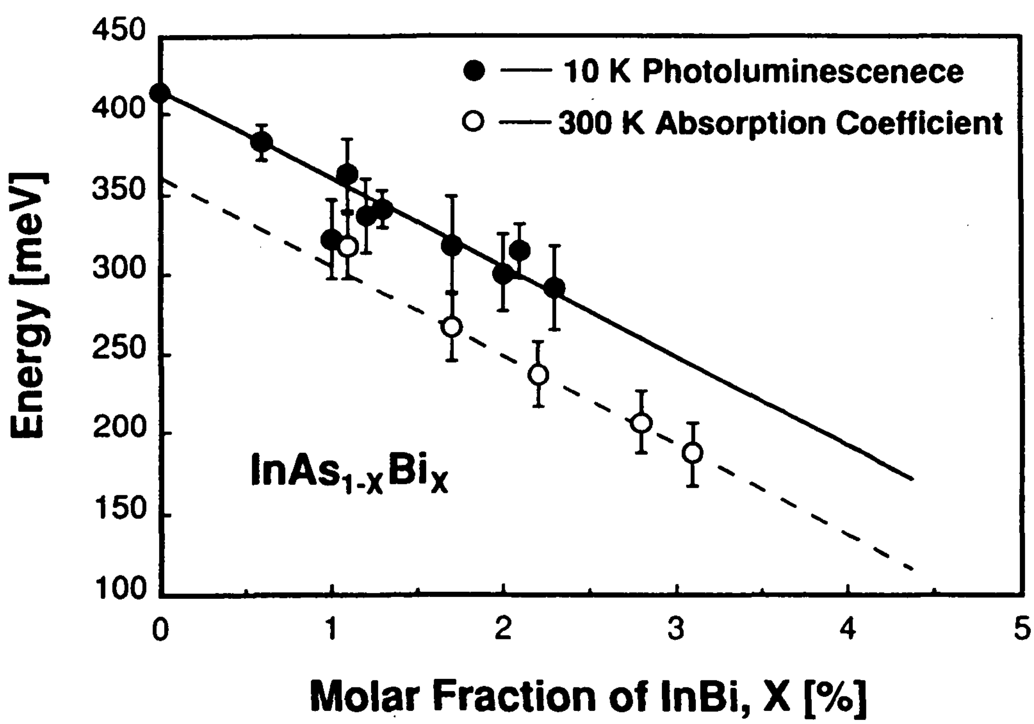


Energy (meV)
450 400 350 300 250
InAs
10 K
InAs0.987Bi0.013
InAs0.980Bi0.020
InAs0.889Sb0.096Bi0.015
PL Intensity (arbitrary units)
2.5 3.0 3.5 4.0 4.5 5.0 5.5
Wavelength (μm)



at.% of Bi: 0
0.6
1.7
2.8
3.1
300 K
InAsBi/InAs
Transmission [%]
Wavenumbers [cm-1]

Fang Fig.5



10 K Photoluminescenece
300 K Absorption Coefficient
InAs1-XBiX
Energy [meV]
Molar Fraction of InBi, X [%]

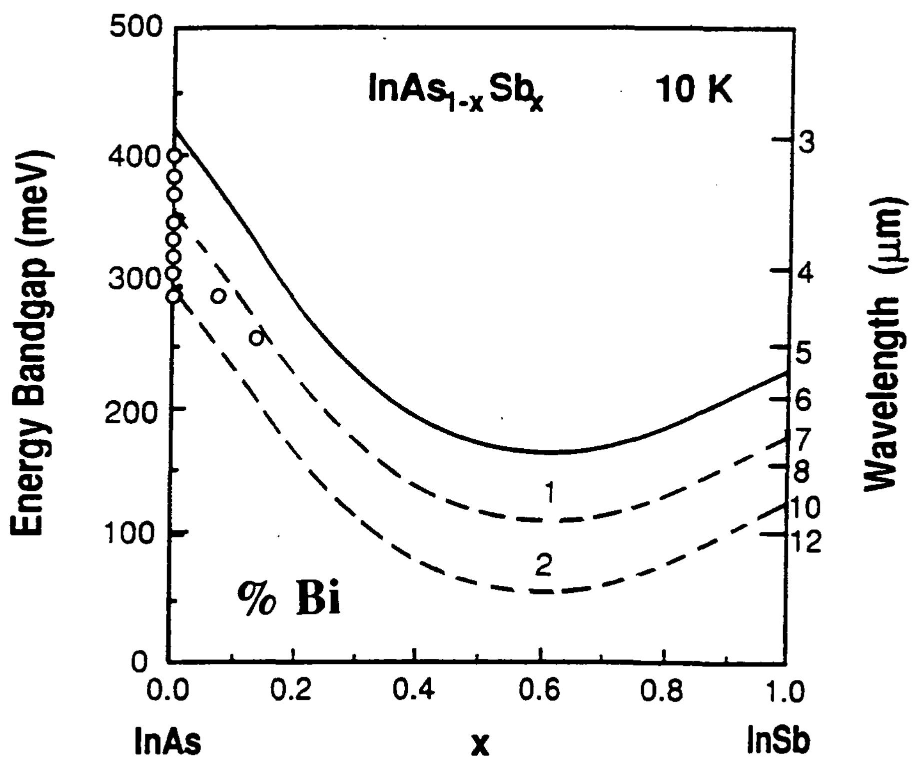
- **EXTRAPOLATION OF DATA TO $InAs_{0.35}Sb_{0.65}$**

  SUGGESTS THAT 2% Bi WOULD YIELD

  GAP EN. $\approx$ 0.034 eV (36 microns)

  MAKING A DIRECT BAND-GAP VLWIR MATERIAL

Energy Bandgap vs. Composition x



STATUS

- OMVPE GROWTHS HAVE BEEN MADE WITH UP

  TO 3.4% Bi AND UP TO 30% Sb

- Bi SEEMS TO BE SUBSTITUTIONAL

  LATTICE INCREASE IS LINEAR,
  BAND GAP SHIFT IS LINEAR,
  X-RAY DATA IS SHARP,
  NO SIGN OF TWO PHASES,
  MORPHOLOGY IS GOOD

• STATUS CONTINUED

- ENERGY DECREASES BY 55meV per % Bi
- a = 6.058 + 0.966 x FOR InAs(1-x)Bi(x)
- LUMINESCENCE SEEN
  - IMPLIES LIFETIME AND ELECTRICAL QUALITY TO BE AT LEAST GOOD
  - BROADENING IMPLIES SOME COMPOSITIONAL VARIATION
- THICKNESS - 8 micron THICK InSb GROWN p-TYPE, 3 E 14

- **PROGRAM FUTURE DIRECTION**

  - OMVPE GROWTH NEAR $InAs_{0.34}Sb_{0.64}Bi_{0.02}$

  - EXTENDED ELECTRICAL AND OPTICAL TESTING TO OPTIMIZE THE GROWTH AND PROVIDE INITIAL OPTICAL DETECTOR DATA

THE LATTER IS A JOINT PROJECT BETWEEN UNIVERSITY OF UTAH AND SANTA BARBARA FOCALPLANE, A COMPANY THAT PROCESSES AND TESTS IR ARRAYS AND MATERIALS

SBF MATERIALS CHARACTERIZATION

PROPERTY	CHARACTERIZATION
BAND-GAP	IR TRANSMISSION
CARRIERS	HALL, CV
EL. TRAPPING	DLTS
CRYSTAL QUALITY	ELECTROREFLECTION
MORPHOLOGY	OPTICAL MIC., SEM
LIFETIME	PC DECAY
SURFACE	MULTI-WAVELENGTH ELLIPSOMETRY

DEVICE AND ARRAY TESTING

DEVICES	TEST
DIODES, VARIABLE AREA VARIABLE PERIMETER GATED, UNGATED	IV, LEAKAGE, RoA, SRV, V BREAKDOWN NOISE, 1/F EL. TRAPPING DLTS
CAPACITORS	CV, GV, Nss, ZERBST, Tgen, Qss, Vfb, Vh
FETS	SURFACE MOBILITY
HALL	MOBILITY, RESISTIVITY, CARRIER CONC.
ARRAYS	RESPONSIVITY VS. WAVELENGTH D*, QUANTUM EFFICIENCY, UNIFORMITY, YIELD